RELIABILITY OF DIFFERENTIAL CORRECTION RECEPTION IN PORTS

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Signals from satellite radionavigational system differential station (DGNSS), designed to improve the accuracy of navigation, have been used for over 30 years. Notwithstanding the fact, until present day the data of how reliably the signals are received in ports is lacking. Experimental data processing has demonstrated that the number of differential correction reception failures is unexpectedly large. These occur due to diurnal changes in the lower layers of ionosphere, due to terrain relief, as well as due to radiointerference. Failures can last for hours. The paper gives an analysis of failure diurnal range characteristics and recommendations to overcome these.

Keywords: GNSS-beacon, differential correction, loss of differential corrections.

The attempt to restore the former navigational communication structure in Russian Arctic sector, based on lighthouses, light buoys, racons, radio beacons and local radio positioning systems can't be admitted as an efficient one. Firstly, it's quite an expensive method, and moreover it no longer can meet contemporary requirements to the accuracy of ship position fixes on the Northern Sea Route. Secondly, there are tested navigation technologies, based on the employment of GNSS (Global Navigation Satellite Systems). Though until very recently only two systems of the kind were operated: Navstar GPS and GLONASS, during the previous two years outer space components of Chinese satellite system named Beidou-2 and the European one named Galileo are being deployed. Using signals generated by Navstar system a shipborne single-frequency navigational receiver determines the ship's position with the accuracy not less than ±5m with the degree of probability being 0.68. Further improvement of the accuracy of ship position fixes is attained through receiving so called differential corrections, transmitted by the shore-based differential stations. This technology was named DGNSS (Differential Global Navigation Satellite Systems).

The need to construct such shore-based stations, transmitting differential corrections (DGPS-beacons), was caused by the introduction of artificial errors into the signals generated by Navstar GPS satellites, which was effected by the US Ministry of Defense. This mode of the GPS system operation, reserved for civilian consumers only, was named the mode of selective availability (SA). The SA mode resulted in worsening ship's fix errors down to ±100m [8]. Thanks to the differential corrections received, the accuracy of ship position fixes could be improved up to ±5m in restricted water area, adjacent to a DGPS station. First experimental DGPS beacon, owned by the US Coast Guard, was deployed in vicinity of New York city (Montauk point, Long Island) in late 1980-s. The technology of transmitting differential corrections to the measured pseudo distances to a satellite became commonly used after 1991. That year Bob hurricane struck the eastern coast of the United States, shifting floating aids to navigation from their positions. Then it created a situation critical to the safety of navigation in the approaches to the port of New York. Repositioning of buoys and perches using traditional technologies applied by the US hydrographers would have taken about three or four weeks. Using experimental shipborne DGPS beacon signal receivers the Coast Guard was enabled to put the marks in their positions within several days [3]. On the 2^{nd} of May at 04:07 GMT (Modified Julian Date 51666) the operation of the Selective Availability mode was ceased by the Decree of the US President Bill Clinton. Upon cancellation of the SA mode as a major source of errors, eliminated by the reception of differential corrections, there remained processes taking place in the transionospheric and transtropospheric channels of satellite signal propagation, as well as errors of satellite ephemeries and those of the satellites' atomic beam frequency standards.

In June 1983 the US Transportation Systems Centre undertook attempts to unify differential stations' operation. They worked out general recommendations to be followed by the manufacturers of the DGPS beacon shore-based equipment and that of the differential correction shipborne receivers [5]. In November the same year the Specialized

Committee 104 (SC 104) of the Radio Technical Committee for Marine Services (RTCM) did a research into the needs of likely consumers of the differential technologies and defined the requirements to the contents of information transmitted, to the information transmission method, as well as the requirements to pseudo satellites. November 1987 witnessed the publication of the first version of Navstar GPS satellite radionavigational system differential subsystem operation standard, called RTCM SC 104 standard. Since that time differential subsystems have been abbreviated as DGPS. The standards were reviewed in March 1988, in February 1989. On January 1, 1990 RTCM Recommended Standards for Differential Navstar GPS Service, Version 2.0 was published. It is this version that served the basis for national standards of a lot of maritime powers that were intending to deploy networks of DGPS beacons and pseudo satellites. In August 1993 the standards were again revised, and on January 3, 1994 a consequent version 2.1 was published [1]. This already contained transmission formats for GLONASS satellite radionavigational system. Since the time the technology for differential corrections' transmission has been called DGNSS.

The differential correction transmission standards, aimed at providing high accuracy and reliability of ship position fixes by the maritime community when using satellite radionavigational system, were adapted by the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) on the authority of the decision by ITU (International Telecommunication Union) [1, 2]. Differential stations, operating under IALA standard, are commonly called maritime ones – MDGNSS.

Since April 2007 a maritime DGNSS station on Povorotny Cape (Nakhodka) has been transmitting signals, which fact promoted the author to make a number of experimental observations with the purpose of assessing ship position fixes' accuracy and a ship's absolute speed when receiving differential corrections. Processing of preliminary observations that were made in July-August, 2008 on board ferry-boat "Brigadir Rishko", made it possible to detect failures in receiving the differential corrections [9]. Neither Russian nor overseas sources available give any materials on the failure in receiving the differential corrections, transmitted by maritime DGNSS. Thus, further experimental observations were undertaken with the aim of identifying the causes of failures and estimating their statistics. This paper is devoted to the observations' processing and the outcome analysis.

In 2010 the author did experimental observations of a marine GPS receiver Furuno GP-37 at the territory of the Ussuriisk Astrophysical Observatory (UAPO), Far Eastern Branch of the Russian Academy of Science. From July 10 till July 18 the GP-37 receiver was continuously kept in the mode of receiving differential corrections from DGNSS station located on Povorotny Cape. The distance from the observation spot to transmitter of the Povorotny Cape DGNSS beacon was 72 miles. Preliminary processing of the data received revealed periods of time when corrections were not received.

In DGNSS beacons operated under IALA standard the transmission of differential corrections through a radio channel is effected by means of Minimum Shift Keying (MSK) technology. To be more exact it is effected using Binary Phase Shift Keying (BPSK). Its essence is coding 0 and 1 of the information transmitted through switching carrier frequency phase. Binary "0" is coded through the phase delay by 90°. Binary "1" is transmitted with phase lead by 90°. The time rate of phase switching determines the speed of a station's information transmission.

While making observations at UAPO the GP-37 receiver output was wired to a laptop, hard drive of which was continuously, second by second, recording throughout the whole period of observations the information in the form of a packet of statements in NMEA 0183 format. In the course of processing the data obtained, only $GPGGA statements were selected for consequent analysis. In these directly after the longitudinal hemisphere there is an indicator by which the differential correction reception status is assessed. Should there be digit "2" right after the longitudinal hemisphere name, the observed coordinates, located in this statement before it, have been obtained accounting differential corrections. Should there be digit "1" instead of "2", the differential corrections have not been received, while the coordinates preceding have been calculated by the receiver off the line. All in all there were registered 654,221 $GPGGA statements with "2" indicator, and 47,796 ones with "1" indicator. Further processing was reduced to calculating the number of $GPGGA statements with indicator "1" in every hour of observations for all days.

Relative frequency n_j of indicator "1" occurrence during every j hour of observations was chosen as criteria for the comparison of differential correction reception reliability.

$$n_j = \frac{1}{3600} \sum_{i=1}^{3600} a_{j_i},$$

where 3600 is the number of registered $GPGGA statements within an hour of observations, a_i is an indicator of lack of correction in i $GPGGA statements, a = 1.

It is understood that n_j can possess a value of from 0, where during a given hour of the day all the ship's position fixes are carried out accounting differential corrections received, to 1, where during a given hour not a single differential correction was received.

The pattern of failure relative frequency distribution per every hour of the day, Vladivostok time, for all the observations can be judged by the relative frequency diagram (Fig. 1).

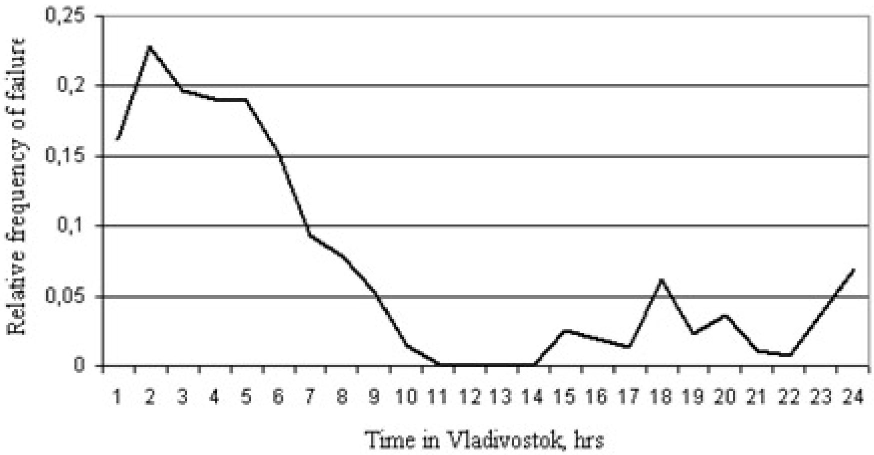

Figure 1. Differential correction reception failure relative frequency diagram, observations made in UPAO in July, 2010

Figure 1 shows that failures have a strongly marked diurnal range. It is seen that correction reception failures fall on the evening hours, night hours and morning hours. Notably, it was night time that was most unfavorable for receiving corrections. Round noon corrections were received without any losses. Failures commence to be encountered closer to sunset, and after 21:00 their numbers increase rapidly up to two o'clock in the morning.

The period of time of from one o'clock in the morning till 5 o'clock in the morning accounts, on the average, for 20 per cent of differential correction failures. Then the number of losses gradually decreases.

As corrections are transmitted in medium-wave band, the explanation for the persistent regularity of the considered failure diurnal range should be sought for addressing the peculiarities of such wave propagation. Media-Frequency Band (MF) of radio waves is unique in that respect that with relatively low transmitter power its signals can be received reliably over distances up to 1,000 km and even more. In dependence of the season, the time of the day and governed by the distance to the radiating antenna, the reception of the signal in this band has some peculiarities that should be taken into account.

The range over which MF radiowaves can propagate is governed by the conditions in the lower layer of ionosphere. These are layer D and layer E. They are characterized by concentration of charged particles and the pattern of the concentration change during a day. The lowest layer D is elevated from 50 km to 90 km over the Earth surface and the peak concentration of from 10^2 to 10^3 per cm^{-3} at the average elevation of 70 km. The concentration maximum in layer D is attained with the Sun passing meridian at a given longitude. In the morning and in the evening the concentration of charged particles is decreased. In contrast to the other ionosphere layers the layer in question features a property of absorbing electromagnetic energy in MF band. Consequently in the daylight there is practically no sky wave in this band. Layers D and E are to a lesser extent affected by the changes in the solar activity and magnetic one. However during strong solar bursts with formidable high-energy X-rays rushing towards the Earth, ionization in layer D is increased, resulting in occasional complete loss of communication in MF band on the lit side of the Earth. It has in recent years been found out that the elevation and consistency of layer D are affected by cyclonic processes in the troposphere [11].

In daylight, when layer D absorbs radiowaves of the MF band, differential corrections transmitted by DGNSS beacon transmitter, can be received hitless over small distances [4, 7]. At nighttime correction will also be reliably received by a shipborne DGNSS receiver over small distances, as there is no sky wave in small distance reception. With great distances at night, when layer D disappears, while layer E will like a natural mirror reflect the electromagnetic energy, interference of sky and ground waves will take place. This phenomenon in the times of common use of radio direction finding was named a night effect [10]. The night effect was regarded as a phenomenon affecting the radio direction finding accuracy, as the signals of the sky and ground waves come to the marine wireless direction finder antenna with different phases. This caused relative bearing scintillation effect and blurring of the minimum radiobeacon signal reading. In case of receiving differential correction the night effect negative influence mechanism is a different one. In the evening and at night time over great distances a ground wave signal, degraded by distance, and sky wave signals, reflected from layer E, come to the shipborne DGNSS receiver antenna. The bottom boundary of layer E will never be ideally even. There always be present irregularities of charged particle concentrations, spaced both horizontally and vertically. Consequently reflection from layer E will be a scattered one. Eventually a shipborne DGNSS receiver antenna will take in through the sky wave path a few signals featuring the same frequency but with the shifted time of phase switching points. Electromagnetic field strength of the sky wave signals at night time predominates over the ground wave strength. The ground wave phase switching points will pass ahead of corresponding switching in the sky wave, as the latter has a longer pathway. Switching of phase in DGPS beacon transmitter carrier frequency occurs at a rate, predetermined by the rate of information transfer (50bps, 100bps, and 200bps). A shipborne DGNSS receiver demodulator is adjusted to this rate. Receiving several signals with out-of-synchronization carrier phase switching points prevents a shipborne DGNSS receiver from decoding the signals received and gating information on differential corrections out of them. That's how differential correction reception is lost as a result of the night effect.

Experimental observations with GP-37 receiver were repeated in Vladivostok on Busse Mountain from June 11 to August 3, 2011. The choice of experimental observation location was governed by the fact that on the flat plots of land in Vladivostok the signals from Povorotny Cape differential station were received in a considerably degraded form. Total time within which the coordinates were being recorded on the laptop hard drive was 1,016.2 hrs (42.34 days). In the course of the initial data processing differential correction failures were also found out. All in all during the observation period of time 3,755,452 observations were registered. Of these there were 3,688,162 observations with differential corrections. Where there was a correction reception failure, the receiver defined the coordinates off the line. There were obtained 67,290 observations in the off the line mode accounting for 1.82 per cent of the number of observations in differential mode.

When making observations at UPAO there were individual instances when failures made it impossible to receive differential corrections within an hour. Observations made in Vladivostok on Busse Mountain featured far fewer failures. The pattern of their diurnal range can be seen in Fig. 2. This shows the diagram of relative frequency of failures, registered in Vladivostok on Busse Mountain from July 24 to July 31, 2011.

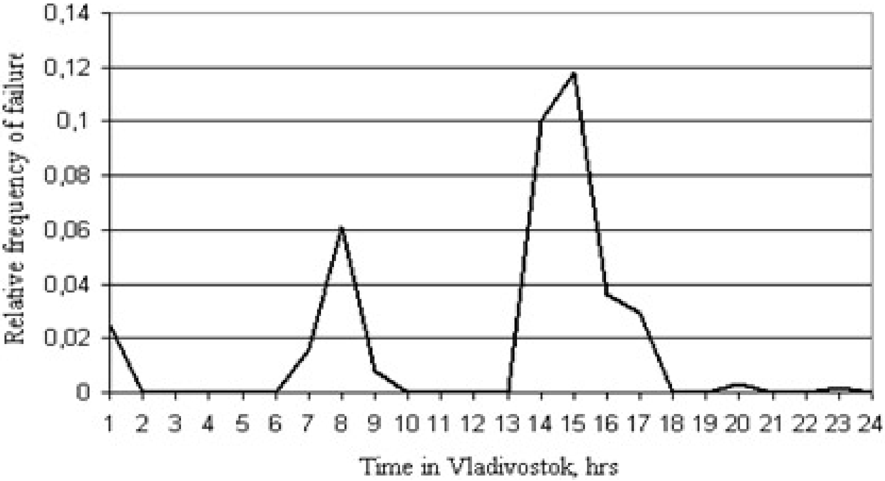

Figure 2. Differential correction reception failure relative frequency diagram, observations made in Vladivostok in the vicinity of Busse Mountain in July, 2011

Analysis of Fig. 2 allows for making the following conclusions. A small number of failures at one o'clock in the morning can be attributed to the night effect. Radio direction finding practice gives examples of the night effect occurrence even at a lesser distances to the radiobeacon. Otherwise the diurnal range of failures in Fig. 2 differs considerably from the Fig. 1 logic, which is accounted for by the night effect. Thus at distances of up to 50 miles from DGNSS beacon loss of differential correction reception is mainly caused by reasons other than the night effect. It is clearly seen in Fig. 1 that extremes of failure distribution empiric density coincides with maximums of business activity, accompanied by intensive transmissions. Consequent analysis has not revealed any dependence of failure frequency on meteorological conditions. The said facts serve the basis for the assumption on radiointerference impact in the course of observations made in June-August, 2011.

From November 6 to November 11, 2011 the author continued his experimental observations of a shipborne GPS-receiver GP-37 operation in Vladivostok. That time the receiver's antenna was stationary mounted on the Maritime State University (MSU) academic building No. 1 on the wall facing NW. Such arrangement resulted in the building masking the signals from Povorotny Cape DGPS beacon. Therefore throughout all the observation period of time differential corrections were never received. Such a phenomenon is in a good accordance with the results of the experiments, published in paper [6].

With the purpose of identifying regularities in occurrence of failures encountered in observations on Busse Mountain in 2011, the author in June 2012 gathered some additional statistical data using the same shipborne GPS receiver GP-37. That time the receiver's antenna was stationary mounted on the face of the MSU academic building No. 1. The building's face look onto SE, therefore the academic building didn't cutoff the signals from Povorotny Cape (Nakhodka Gulf) DGPS beacon. The GP-37 receiver was continuously kept in the mode of automatic reception of differential corrections. The experiment was held from June 18 to June 28, 2012 without any stops. All in all 865,301 detections of geodedic coordinates during 240.36 hrs of continuous observation. Of these 7,233 (0.8359%) detections fall on such condition of the receiver, when it was unable to determine the coordinates, as there were less than three Navstar GPS satellites within its radiovisibility area. Despite the absence of physical obstacles to the Povorotny Cape differential station signal propagation and with its uninterrupted operation 278,408 (32.1747 per cent) of position fixes took place without differential correction reception. And only in 579,660 instances (66.9894 per cent) observations were made with corrections received.

During the first stage of obtained data processing relative failure frequency for each hour of every day of observations were calculated. As a rule, at the beginning and the end of a period of 24 hours the number of failures was relatively low, the only exceptions being June 26, 27 and 28. A considerable rise in Povorotny Cape differential station signal failures then could be accounted for by cyclonic activity that caused night effect. In the middle of the day the number of differential correction losses increases. It turned out that on the 27th of June from 00:00 till 16:00 differential correction reception in Vladivostok was not possible. Diurnal failure distribution in observations made in November 2012 is represented in Figure 3.

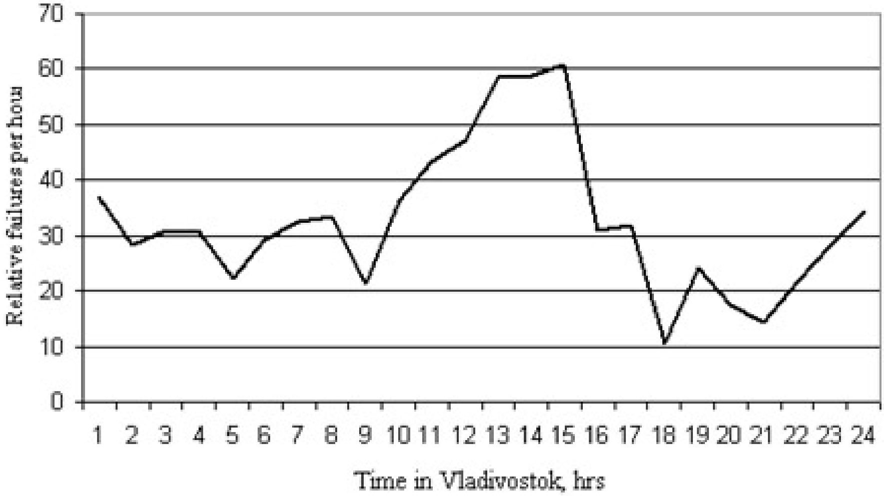

Figure 3. Failure relative frequency per hour of differential correction reception in June 2012, MSU, Vladivostok

It is obvious that Fig. 3 demonstrates maximum values of correction reception failure in the middle of a workday. One can easily see that the number of failures rises from 20 per hour at 10 o'clock to 60 per hour at 16 o'clock. This is consistent with the data obtained in 2011 on Busse Mountain. If one takes an assumption that the number of failures is influenced by the processes pertaining to the occurrence of radiointerferences during business activity in the daylight, then one should expect a decrease in the number of failures at weekend. Observation processing has proved that the failures frequency tends to decrease by the end of the week. In the middle of the working week it is increasing. That was the reason for the highest intensity of failures observed on Wednesday, June 27, resulting in impossibility to receive differential corrections in Vladivostok. These facts cause doubt about the expedience of developing DGPS-technologies in Vladivostok and its vicinity unless the causes for radiointerference occurrence are eliminated.

In conclusion it is necessary to focus on the following:

1. Sailing of vessels in port water areas requires particular accuracy in position fixing which is achieved by receiving differential DGNSS signals. Experimental observation data processing has allowed for determining that the terrain relief, night effect, and radiointerference can keep the serviceableness of DGNSS to a minimum.

2. One of the measures aimed at differential correction reliability improvement can be observing discipline of radiotraffic in port areas.

3. Differential correction transmission under IALA standard in MF band seems to be ineffective. Therefore it is necessary to investigate the reliability of other methods of differential correction propagation by means of radio in port areas.

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